

Resistance of mammal assemblage structure to dryland salinity in a fragmented landscape

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Abstract

The impact of secondary environmental disturbance on native mammals is rarely considered. What little evidence exists, suggests that native mammal assemblages are resistant to secondary impacts. The Wheatbelt of Western Australia (WA) is a large fragmented region, resulting from historic land clearing for agriculture. Dryland salinity is a secondary environmental disturbance occurring in the Wheatbelt, as a result of land clearing, caused by rising groundwater tables and mobilisation of regolith salt to the soil surface. I used trapping and transect surveys to assess how the abundance of non-volant native, invasive and agricultural mammals related to salinity and other environmental attributes. I found support for the hypothesis that native mammals are resistant to the effects of compounding environmental change. I also found that abundance of introduced mammals were unrelated to salinity, except sheep *Ovis aries* (Linnaeus 1758, Bovidae), which exhibited reduced abundance in saline areas, relating to pasture availability. Instead, individual and assemblages of mammals exhibited associations with other environmental factors, which is consistent with other studies. Findings here support other studies which indicate native mammals that survive primary environmental change are resistant to further impacts. Resistance of native mammals to secondary environmental impacts may be a widespread phenomenon.

Keywords: Resistance, environmental change, dryland salinity, secondary salinisation, distribution, remnant vegetation, Western Australia, Wheatbelt

Introduction

The effect of discrete environmental impacts, such as deforestation and agriculture, on an assemblage of organisms has been widely studied. Specialist taxa, which are often native, tend to be negatively affected, whereas generalist and invasive taxa typically benefit (for example, Bennett 1993; Kaminski *et al.* 2007; Kitchener *et al.* 1980; Pearce & Venier 2005; Stephenson 1995; Suntsov *et al.* 2003; Torre *et al.* 2007; Umetsu & Pardini 2007). The effect of sequential environmental impacts on the same ecosystem has been considered less often, particularly for mammals. Of the few mammal studies that have considered sequential impacts, assemblages appear to be resistant to secondary environmental impacts (Larsen *et al.* 2007; Michalski & Peres 2007). For example, Larsen *et al.* (2007) found the impacts of timber harvesting and fire on small mammals were similar, but not additive; and Michalski & Peres (2007) found that assemblages of medium to large sized mammals which were already affected by fragmentation in tropical forests did not respond further to fire. Here, I examine the relationship of individual species and assemblages of mammals in a fragmented landscape, in

the southwest of Western Australia (WA), to a secondary environmental impact, dryland salinity, and other environmental attributes.

Mammals form a charismatic part of the biota of the southwest corner of Western Australia, which is one of the world's 25 biodiversity hotspots (Keighery *et al.* 2004). The inland region of southwest WA (the Wheatbelt, 20 million hectares) has been extensively cleared for agriculture (grazing and cereal growing). Overall 74% of the natural land cover has been cleared (McKenzie *et al.* 2003; McKenzie *et al.* 2004) and assemblages of mammals that remain are composed of relic, agricultural and invasive species (Burbidge & McKenzie 1989). Seventeen native mammals are now considered extinct in the Wheatbelt region and at least 10 mammals have been either introduced for agriculture or are invasive (Burbidge & McKenzie 1989; Burbidge *et al.* 2004; Kitchener *et al.* 1980; McKenzie *et al.* 2002). A secondary consequence of land clearing in the Wheatbelt has been a rise in groundwater tables (due to a reduction in the number of deep rooted tree species that maintain low water tables via high rates of evapotranspiration). Rising groundwater tables have mobilised large regolith salt deposits to the soil surface. There has been a twenty fold increase in salinity in the Wheatbelt (termed "dryland salinity") since European settlement (Halse *et*

al. 2003). Currently more than one million hectares are affected by dryland salinity and this is expected to expand two to four fold by 2050 (George *et al.* 2006; Jardine *et al.* 2007).

Dryland salinity has numerous environmental impacts that are relevant to the ecology of mammals. Vegetation structure is impacted by salinity (Cramer & Hobbs 2002; Gibson *et al.* 2004; Lyons *et al.* 2004; Seddon *et al.* 2007), potentially affecting habitat for all mammals and food availability for herbivores. Salinity also influences the occurrence of vertebrate and invertebrate fauna (McKenzie *et al.* 2003; McKenzie *et al.* 2004), which may alter food availability for carnivorous, omnivorous and insectivorous mammals. Physiologically, saline water may also exert pressure on osmoregulation and the ability of mammals to persist and/or survive in saline areas (Kennear *et al.* 1968; Patrick *et al.* 2001; Purohit 1967, 1971). To date, few studies have examined the effects of saline habitats on mammal populations. Those studies that have documented associations between salinity and mammal populations have focused on small mammals and found the abundance and diversity of taxa to be unaffected by salinity (Burbidge *et al.* 2004; McKenzie *et al.* 2003; Smith *et al.* 1997). This study builds on previous research (Burbidge *et al.* 2004; McKenzie *et al.* 2003) by considering a range of sizes of non-volant terrestrial mammals and the relative influence of salinity on native and introduced species in a highly fragmented landscape. Dryland salinity represents a secondary environmental degradation for native mammals only.

In this study, I hypothesise: native and introduced mammal fauna will exhibit resistance to secondary disturbance of dryland salinity and assemblage structure is more related to other environmental variables that are known to affect their distribution and abundance. I inherently assume mammal communities measured here have adapted to fragmentation and, in saline sites, fragmentation and salinity. Thus the effect of secondary disturbance on native mammals equates to the difference in population structure between saline and non-saline area. I deem this assumption reasonable because regions surrounding all sites in this study have been fragmented for at least 40 years, and saline sites are known to have been saline for not fewer than five years (Burbidge & McKenzie 1989; Keighery *et al.* 2004 and references therein), which exceeds or approximately equates to the lifespan of many mammal species recorded here (Strahan 1988). Because mammal abundance may vary between seasons, I also examine this variability with respect to my hypothesis.

Methods

Study area

This study was undertaken in the Great Southern meteorological district of the WA Wheatbelt (Figure 1). The study area has a Mediterranean climate with hot dry summers and mild wet winters. Annual rainfall declines from approximately 600mm at the western boundary of my study sites to 350mm for the most easterly sites (Australian Bureau of Meteorology). Approximately 80–90% of the study area has been cleared for agriculture (Halse *et al.* 2004). Trapping and transect survey sites

were separated by 5km or more, located in remnant native vegetation and were chosen to correspond with locations previously used by the WA Department of Environment and Conservation to assess the impacts of dryland salinity (Keighery *et al.* 2004).

Surveys

Surveys of mammals were undertaken using a combination of transect surveys and trapping across 12 sites (see Figure 1 for site names and coordinates). Surveys were conducted from September to December 2006 (spring) and February to May 2007 (late summer and autumn). Surveys followed ASM guidelines (Journal of Mammalogy 88: 809–823, 2007) and were ethically approved by the University of Western Australia Animal Ethics Committee (06/100/566).

Transect surveys were used to record mammal species which were unlikely to be captured by trapping, such as macropods, foxes and agricultural animals. Surveys were undertaken during the hour immediately after dawn and in the half hour before dusk, to correspond to the period of highest activity of macropods and other crepuscular species (Arnold *et al.* 1989; Hill *et al.* 1988; Priddel 1986). Surveys consisted of walking an established line transect through remnant vegetation or slowly driving a transect along a farm track/dirt road through or adjacent to the remnant. A minimum of one walking and one driving transect were performed at a site on each survey occasion. Transect surveys at each site were replicated 6–8 times (see Figure 1 for number of surveys at individual sites) and averaged to account for temporal and spatial variability in observations. Equal numbers of dawn and dusk surveys were conducted at each site. Consecutive surveys of a site were separated by a minimum of four days, to avoid survey bias in mammal behaviour and distribution. In total, 87 surveys were conducted across all sites, consisting of 233 individual transects.

On each transect, I measured the total distance [with a calibrated pedometer (VIA™ Step, New Balance®, Fenton, Missouri) or vehicle odometer (± 10 meters)], bearing, observational area within each habitat type and entire transect [transect length within habitat type \times distance over which sight-ability of animals was reliable for each habitat type (50 meters in vegetation and forestry and 200 meters on roads or across agricultural land) summed for the total transect], mammal species, distance and bearing to each observed mammal. To minimise counting the same animal twice, transects were separated by greater than 200 metres. In rare cases where an animal was suspected of being counted twice, the result was discarded from one of the surveys. Sheep, *Ovis aries* (Linnaeus 1758, Bovidae) that were in paddocks surrounding the remnant vegetation were also counted during surveys. Numbers of sheep were approximated when individuals could not be reliably counted (typically when flocks exceeded 50). The abundance of mammals at each site was calculated as the number observed per hectare (number observed/observational area across all transects).

Trapping grids were laid in areas of remnant vegetation at each site. I used box traps (90x90x350mm, Elliott Scientific Equipment, Upwey, Victoria) and wire cage traps (220x220x550mm, Sheffield Wire Products, Welshpool WA). Both trap-types were baited with peanut

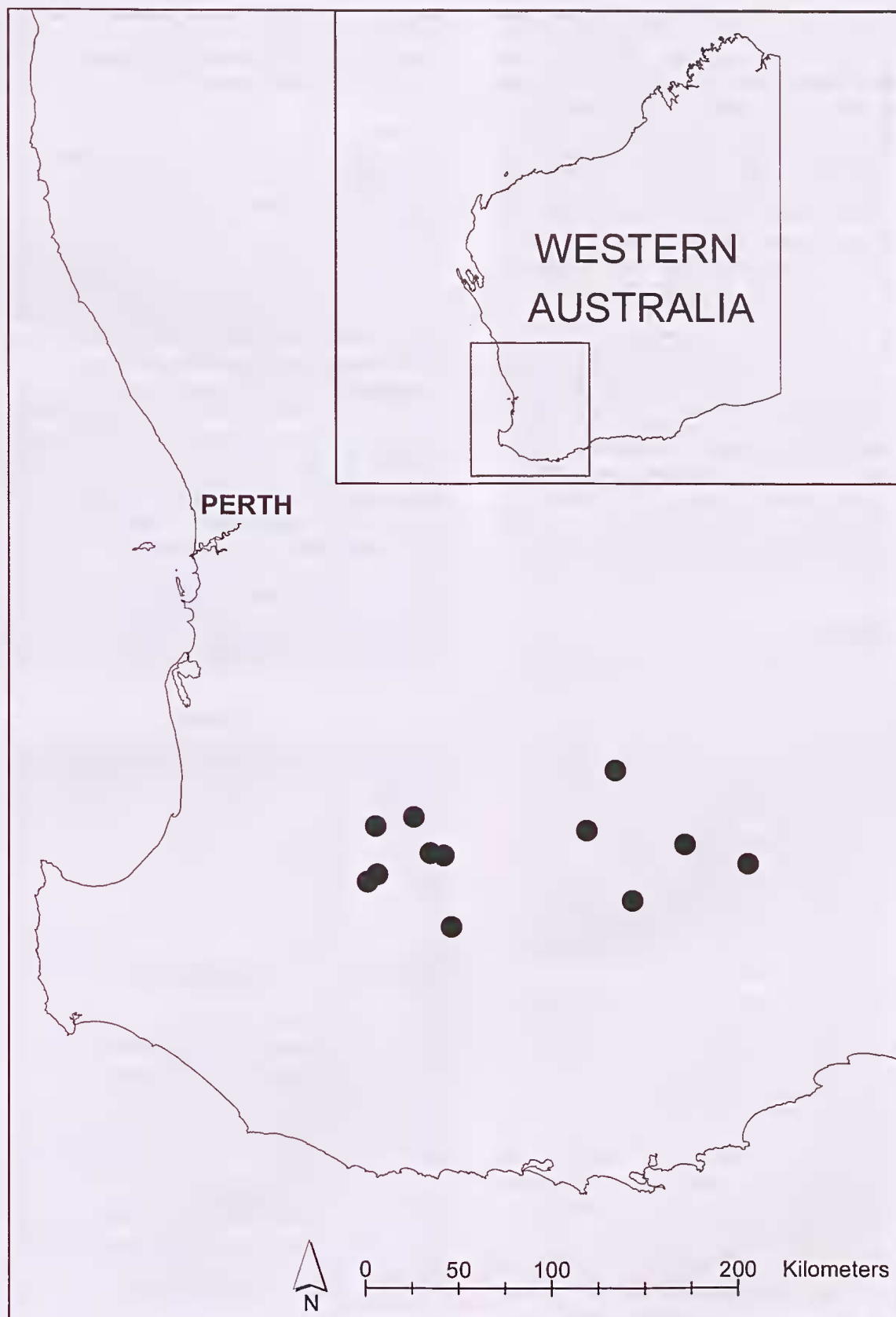


Figure 1. Sites surveyed for mammal fauna in the Wheatbelt of southwest WA. Site names, their coordinates and survey effort per site (number of transect and trapping surveys respectively): DA02, lat -33.35628 long 116.62067 (7, 2); DA03, lat -33.31329 long 116.80671 (7, 2); DA05, lat -33.48809 long 116.88669 (7, 2); DA07, lat -33.49884 long 116.95164 (8, 2); DA10, lat -33.59043 long 116.63058 (7, 2); DA12, lat -33.62621 long 116.58273 (7, 2); DA13, lat -33.84380 long 116.98703 (8, 2); DU02, lat -33.08636 long 117.77947 (6, 2); DU06, lat -33.37755 long 117.64134 (8, 2); DU08, lat -33.71999 long 117.86499 (8, 2); DU09, lat -33.44393 long 118.11712 (8, 2); DU13, lat -33.54058, long 118.42258 (6, 2).

butter (Sanitarium®, New South Wales) and rolled oats (Asia/Pacific Wholesalers Pty. Ltd., Parramatta, New South Wales). Box traps were set on a 7x10 grid ($n = 70$) with 8 metres between each row of traps. Cage traps were placed next to every second box trap along four of the trap lines ($n = 20$). Nesting material was used to insulate box traps; each cage trap was insulated by covering with a hessian bag. Traps were set just before dusk, then cleared and closed shortly after dawn. Each site was trapped twice (once in spring and once in autumn) for three consecutive nights, giving a total of 6480 trap nights. Trapped animals were identified to species, marked using blue food colouring (Queen Fine Foods Pty. Ltd., Alderley, Queensland) and released.

Trapping was used to estimate trap success (the number of unique individuals trapped per 1000 trap nights) of any mammal within the trapping grid. Trap success, or the related abundance estimate "minimum number alive", are conservative measures of abundance for small mammals, and common measures of abundance used for species such as the introduced domestic mouse *Mus domesticus* (Schwarz & Schwarz 1943, Muridae: syn. *Mus musculus* Linnaeus 1758; McKenzie *et al.* 2003; Ruscoe *et al.* 2001). At all sites, the maximum diversity of trapped mammals was achieved within the first two nights of trapping.

Environmental data

To examine how mammals were associated to salinity and other environmental data, soil ($n = 8$), vegetation ($n = 5$) and geomorphic ($n = 5$) variables, for each of the 12 sites, were obtained from the WA Department of Environment and Conservation (Keighery *et al.* 2004 and references therein: see Table 1 for variables and definitions). Briefly: soil variables consisted of standard texture and chemical values collected at a depth of 2–10cm (after removal of surface litter) from 20–30 points per site, then bulked for analysis; vegetation variables were subjective assessments of habitat, divided into categories, using methods modified from Newsome & Catling (1979); geomorphic variables included subjective categories of salinity impacts and risk, and variables relating to position in the landscape.

Vegetation and geomorphic variables, despite being subjective, provided good estimates of habitat (within remnants) and position in the landscape. Categories of salinity impacts (adjSAL and Saltype, Table 1) at sites followed those described by Keighery *et al.* (2004) and references therein, and further developed by Carver *et al.* (2009) to encompass the broader area (within and surrounding remnants) in which surveys were conducted. Briefly, adjSAL: (1) non-saline, due to absence of stags and samphire, high position in the landscape, low water table, high soil permeability, and/or the low salt store in the regolith ($n = 4$); (2) low salinity impact or risk, due to stags and samphire being uncommon, small variation in local relief and geology where rising water tables may not affect all the land area, or where rising watertables are not currently saline, and the salt store in the regolith is low ($n = 2$); (3) intermediate salinity impacted, due to common occurrence of stags and samphire, salinity occurring in limited areas, or from shallow saline groundwater with a rising trend ($n = 1$); and (4) saline land, due to widespread occurrence of

stags and samphire and obvious salt effects (such as large patches of bare earth) in the area ($n = 5$). For Saltype (Table 1) sites were specifically categorised as: not saline ($n = 6$) or salinity affected ($n = 6$).

Analyses

For mammals that occurred at three or more sites, I initially examined if my estimates of mammal abundance differed between spring and autumn for both transect and trapping surveys (number of mammals surveyed per hectare and trap success per 1000 trap nights referred to as abundance here forth). Pairwise student t-tests were used to examine differences between spring and autumn trapping sessions. Abundance of mammals did not differ between seasons (see results). Data for each species were pooled and used for all subsequent analyses.

Analyses of the relationship of assemblages and species of mammals to salinity, and other environmental variables, were based on the assumption that variation in the spatial abundance of mammals and their assemblages reflect underlying correlations with environmental factors (Austin 1991). Dryland salinity is known to influence plant species occurrence, abundance and species composition (Cramer & Hobbs 2002; George *et al.* 1999; Lymbery *et al.* 2003; Seddon *et al.* 2007). This interrelationship may confound analyses between salinity, vegetation and abundance of mammals. Accordingly, relationships among environmental variables were assessed by Spearman correlation.

Table 1

Environmental attribute codes. Data and codes derived from Keighery *et al.* (2004) and references therein, with permission from authors. adjSAL and Saltype further developed by Carver *et al.* (2009).

Code	Attribute
Clay	% clay
Silt	% silt
Sand	% sand
Drainage	Soil drainage in six classes (poor – rapid)
pH	
OrgC	Organic carbon %
P	Available (HCO_3) phosphorus (ppm)
K	Available (HCO_3) potassium (ppm)
TreeCanp	Tree canopy in three categories
ShrubCov	Shrub cover in three increasing categories
GrndHerb	Ground herbs in three categories (sparse – dense)
GrndStuf	Ground cover by leaf litter, rocks and fallen wood in three increasing categories
HCS	Habitat complexity score in ten categories
Landform	Twelve position categories (valley floor and deposits rising to plateau)
Slope	Slope in five categories (flat – steep)
EC	Electrical conductivity (mS m^{-1})
adjSAL	Salinity in four classes (non-saline, low salinity, intermediate salinity, saline)
Saltype	Salinity type in two classes (not saline, salinity affected)

Measures of vegetation in this study were of general structure and not taxa specific (see Table 1). For the singular case where a vegetation variable was related to a salinity variable (GrndStuf and Saltyp, see Table 2), subsequent comparisons of mammal data with ground cover were made using the residuals.

The distribution and abundance of *O. aries*, in this study, is influenced by intensive management. Nevertheless, the distribution and abundance of this species is still constrained by environmental and physiological limitations (e.g., food production and osmoregulation in saline environments). Therefore, *O. aries* were included in analysis of geomorphic and soil variables, but vegetation variables were not analysed as sheep did not occur within remnant vegetation.

The similarity of mammal assemblages between sites was examined by Non-Metric Multidimensional Scaling (NMDS) in PRIMER v6 (PRIMER-E Ltd: Plymouth, U.K.). NMDS were carried out on Bray-Curtis similarity matrices from square root transformed and standardised abundance data. A Spearman rank correlation (ρ : the BIOENV procedure in PRIMER v6) was used to assess which combination of environmental variables best explained the multivariate variation in assemblage structure.

Relationships between abundance of individual mammal species, for species that occurred in three or more sites, and environmental variables were examined using linear regression. Additionally, a power analysis

was used to determine the probability of detecting a significant relationship between salinity and abundance of mammals. For parametric univariate analyses in this study, data were examined for normality (Shapiro-Wilk's test of normality) and equal variances (Levene's test) prior to analysis. Data which were not normal or had unequal variances were normalised by log transformation. Analyses were undertaken using SPSS 15.0 (SPSS Inc. Chicago, U.S.). To avoid committing Type-I statistical error, analyses were not adjusted for multiple comparisons (Nakagawa 2004).

Results

Environmental variables

Salinity was greater at sites which were flat, low in the landscape and with poor drainage (Table 2). General measures of vegetation were unrelated to site salinity, except ground cover, which was negatively related to salinity type (Table 2)

The occurrence and abundance of mammals

Eight mammals were observed during transect surveys [native species: Western Grey kangaroo *Macropus fuliginosus* (Desmarest 1817, Macropodidae); Brush wallaby *Macropus irma* (Jourdan 1837, Macropodidae), and introduced species: rabbit *Oryctolagus cuniculus* (Linnaeus 1758, Leporidae); sheep

Table 2

Significant Spearman correlations between environmental variables. See Table 1 for definitions.

Variable	Correlation	ρ	P	Variable	Correlation	ρ	P
Clay	Sand	-0.713	0.009	K	Silt	0.767	0.004
	pH	0.611	0.035		Sand	-0.622	0.031
Silt	Sand	-0.697	0.012		EC	0.676	0.016
	P	0.763	0.004		Drainage	-0.790	0.002
	K	0.767	0.004	ShrubCov	Sand	-0.637	0.026
	EC	0.746	0.005	GrndHerb	HCS	0.650	0.022
	Drainage	-0.583	0.047	GrndStuf	pH	-0.662	0.019
	Landform	-0.605	0.037		Saltyp	-0.617	0.033
Sand	Clay	-0.713	0.009		HCS	0.607	0.036
	Silt	-0.697	0.012	HCS	GrndHerb	0.650	0.022
	pH	-0.730	0.007		GrndStuf	0.607	0.036
	K	-0.622	0.031	Landform	Silt	-0.605	0.037
	ShrubCov	-0.637	0.026		EC	-0.630	0.028
Drainage	Silt	-0.583	0.047		Drainage	0.725	0.008
	K	-0.790	0.002	Slope	adjSAL	-0.702	0.011
	EC	-0.768	0.004	EC	Silt	0.746	0.005
	Landform	0.725	0.008		P	0.754	0.005
pH	Clay	0.611	0.035		K	0.676	0.016
	Sand	-0.730	0.007		Saltyp	0.580	0.048
	Saltyp	0.606	0.037		Drainage	-0.768	0.004
	GrndStuf	-0.662	0.019		Landform	-0.630	0.028
OrgC	P	0.597	0.041	adjSAL	Saltyp	0.920	<0.001
P	OrgC	0.597	0.041		Slope	-0.702	0.011
	EC	0.754	0.005	Saltyp	pH	0.606	0.037
					EC	0.580	0.048
					adjSAL	0.920	<0.001
					GrndStuf	-0.617	0.033

Table 3

For mammals that occurred at three or more sites: the number of sites each mammal species was detected and average abundance (number per hectare) and trap success (number/1000 trap nights) (mean \pm SE) in spring and autumn. Student t-tests to detect differences in abundance and trap success between seasons.

	Spring Occurrence	Abundance/trap success Mean	SE	Autumn Occurrence	Abundance/trap success Mean	SE	$t_{1,22}$	P
<i>M. fuliginosus</i>	12	0.199	0.04	12	0.239	0.066	0.483	0.634
<i>O. cuniculus</i>	9	0.015	0.005	7	0.009	0.005	0.862	0.398
<i>O. aries</i>	11	1.516	0.338	12	1.164	0.182	0.959	0.348
<i>V. vulpes</i>	2	0.001	0.001	6	0.004	0.001	1.323	0.199
<i>M. domesticus</i>	9	55.952	16.779	7	22.619	7.891	1.258	0.222
<i>T. vulpecula</i>	2	20.833	17.556	3	25.000	17.604	0.175	0.863

O. aries; goat *Capra hircus* (Linnaeus 1758, Bovidae); horse *Equus caballus* (Linnaeus 1758, Equidae); pig *Sus scrofa* (Linnaeus 1758, Suidae); and fox *Vulpes vulpes* (Linnaeus 1758, Canidae)] and four species were trapped [native species: Brushtail possum *Trichosurus vulpecula* (Kerr 1792, Phalangeridae); Mitchell's hopping mouse *Notomys mitchelli* (Ogilby 1838, Muridae); Red-tailed phascogale *Phascogale calura* (Gould 1844, Dasyuridae), and the introduced house mouse, *Mus domesticus*]. *Ovis aries*, *Capra hircus* and *Equus caballus* were agricultural animals and the remaining species were either wild native or feral. No mammal was recorded by both transect and trapping surveys. Relatively few native mammals were trapped or observed. *M. fuliginosus* was the most widespread native species recorded (Table 3). *Trichosurus vulpecula* was recorded at the highest abundance for native mammals, but was only trapped at three sites (Table 3). *Macropus irma* was recorded in autumn at one site only. *Notomys mitchelli* and *P. calura* were both abundant (> 0.5 per hectare), but occurred at only one and two sites respectively. Of the invasive and agricultural mammals, *O. aries* were the most widespread and *Mus musculus* the most abundant (Table 3). The remaining introduced species (*C. hircus*, *E. caballus*, *S. scrofa*) were uncommon (occurring at one site each), except for *O. cuniculus* and *V. vulpes*, which were detected infrequently at ten and six of the twelve sites,

respectively (Table 3). For both trapping and transect surveys, the average abundance of each species did not differ between spring and autumn (Table 3).

Mammals, salinity and other environmental variables

Assemblage structure of mammals was similar for ten of the twelve sites (clustered together on the NMDS plot, Figure 2), predominantly composing of *M. fuliginosus*, *O. cuniculus*, *O. aries* and *M. domesticus*. Of these ten sites, three appeared distinct, likely due to the additional occurrence of *T. vulpecula* (Figure 2). Assemblage structure of mammals for the remaining two sites was distinct, due to the absence of *M. domesticus* and presence *P. calura* (Figure 2). These two sites were different from each other, due to the presence of *N. mitchelli* at one site (Figure 2). The assemblage structure of mammals was best explained by three environmental variables (Spearman correlation from BIOENV procedure, $\rho = 0.460$): phosphorus, slope and ground herb cover.

For mammals which occurred at three or more sites, abundance of *O. aries* only were related, negatively, to increasing salinity category (Table 4, Figure 3c). The probability of detecting a significant effect of salinity on abundance of most mammal species was small, with the

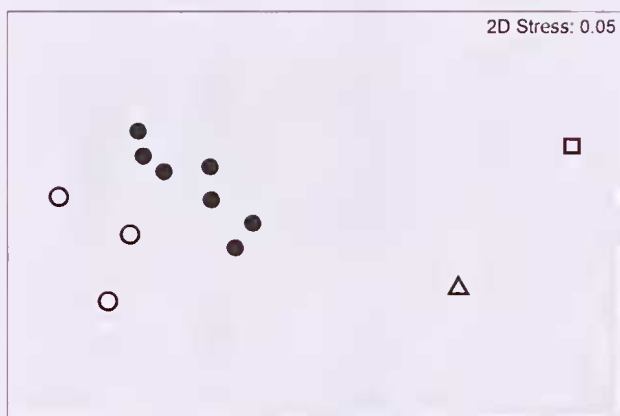


Figure 2. NMDS of mammal assemblages ($n = 12$) based on trapping and transect data combined. Sites that are circles are similar in assemblage composition, with open circles representing sites in which *T. vulpecula* occurred. The open square and triangle sites differed from other sites, due to the absence of *M. domesticus* and presence of *P. calura*. The open square represents a site that also contained *N. mitchelli*.

Table 4

Significant linear regressions between the abundance (number per hectare) and trap success (number/1000 trap nights) of mammals at sites ($n = 12$) and environmental variables. See Table 1 for definitions of environmental attribute codes.

	Predictor	r^2	Regression Coefficient	SE	$F_{1,10}$	P
WGK*	GrndHerb	0.486	0.119	0.039	9.465	0.012
Rabbit	Clay	0.400	0.029	0.011	6.663	0.027
	Sand	0.338	-0.001	<0.001	5.108	0.047
Sheep	EC	0.339	-0.409	0.181	5.123	0.047
	adjSAL	0.720	-0.418	0.083	25.665	<0.001
	Saltyp	0.696	-1.086	0.227	22.898	<0.001
	Slope	0.453	0.702	0.244	8.270	0.017
Mouse	GrndStuf	0.452	35.204	12.267	8.236	0.017
	K	0.331	61.362	27.557	4.958	0.050
	Drainage	0.377	-12.663	5.136	6.051	0.034
Possum	Silt	0.470	172.377	57.899	8.864	0.014
	Sand	0.807	-8.320	1.286	41.865	<0.001
	P	0.935	7.702	0.642	143.904	<0.001

* WGK = Western Grey kangaroo, *M. fuliginosus*

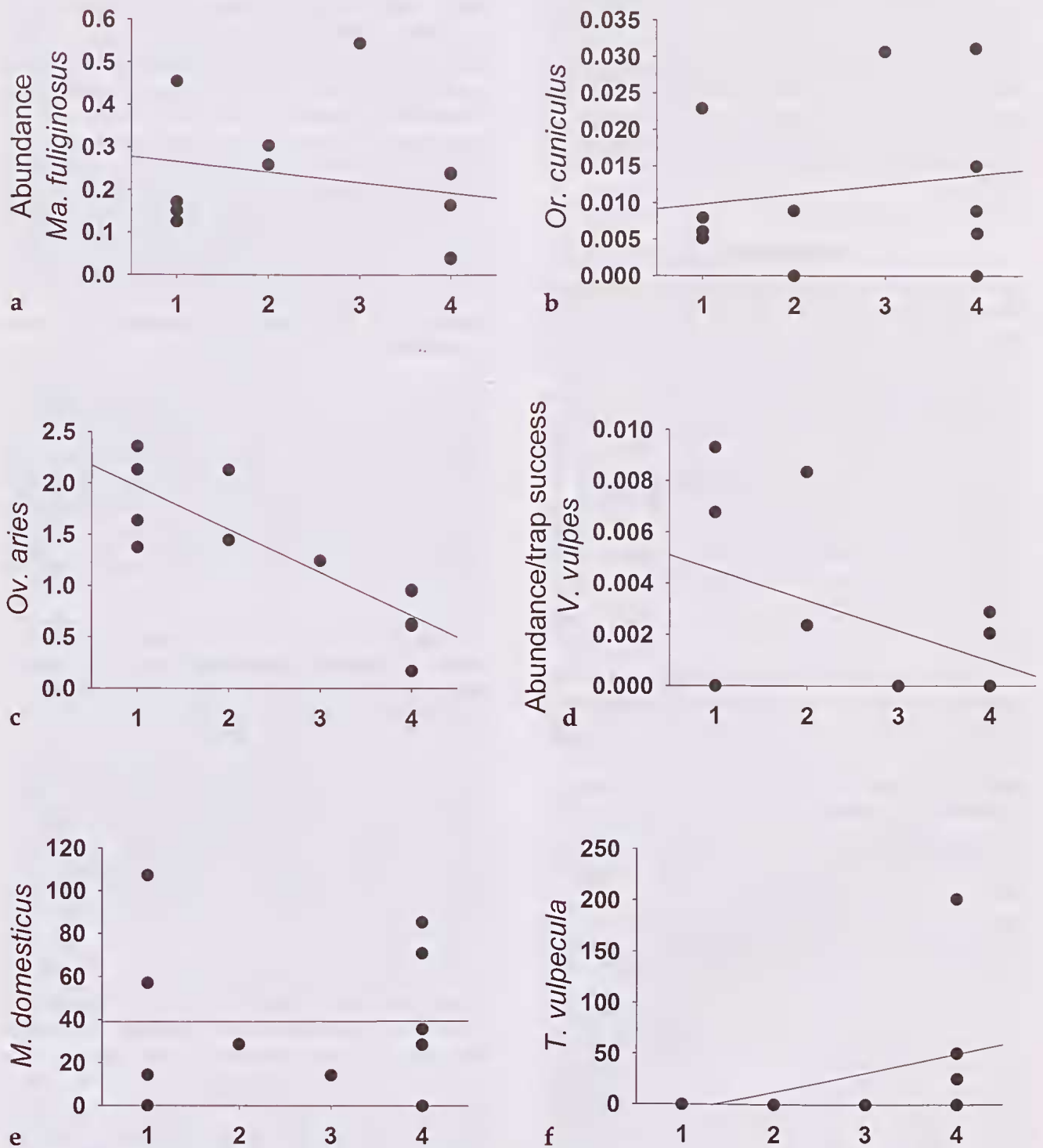


Figure 3. Relationships between the abundance (number per hectare) and trap success (number/1000 trap nights) of mammals with adjSAL category (Table 1). Linear regressions and power analysis for probability of detecting a significant salinity effect: (a) $r^2 = 0.049$, $F_{1,10} = 0.517$ $P = 0.488$, power = 0.106; (b) $r^2 = 0.028$, $F_{1,10} = 0.286$ $P = 0.640$, power = 0.079; (c) $r^2 = 0.720$, $F_{1,10} = 25.665$ $P < 0.001$ (regression coefficients (\pm SE), predictor $-0.418(0.083)$ and constant $2.385(0.240)$), power = 0.999; (d) $r^2 = 0.214$, $F_{1,10} = 2.720$ $P = 0.130$, power = 0.428; (e) $r^2 = 0.001$, $F_{1,10} = 0.001$ $P = 0.983$, power = 0.046; and (f) $r^2 = 0.197$, $F_{1,10} = 2.454$ $P = 0.148$, power = 0.346.

possible exception of *V. vulpes* (Figure 3), suggesting there was little discernable relationship between salinity and abundance of most mammals (except *O. aries*) in this study. Abundance of *M. fuliginosus* and *M. domesticus* were related to vegetation variables (Table 4). Abundance of *V. vulpes* were not significantly related to any environmental variable (Table 4, Figure 3d), but there was a positive trend with ground cover ($r^2 = 0.005$, $F_{1,10} = 4.947$ $P = 0.0503$). Abundance of *O. cuniculus*, *M. domesticus* and *T. vulpecula* were related to soil variables (Table 4).

Discussion

Few studies consider the effect of secondary environmental impacts on mammals. Here, I evaluated how abundance of mammals was related to dryland salinity (a secondary environmental impact) and other environmental variables in a fragmented landscape. Overall, the abundance of native mammals, for which dryland salinity represents a secondary environmental impact, was not associated with salinity, suggesting that these taxa are resistant to the secondary environmental degradation, brought about by dryland salinity. In contrast, salinity was explanatory of *O. aries* abundance. It is acknowledged that *O. aries* are extensively managed and, as such, my estimates of their abundance reflect management. This relationship is unsurprising, because saline land supports lesser amounts of pasture and consequently agricultural production is lower (Lloyd 2001).

Widespread clearing and habitat fragmentation are characteristic features of the Wheatbelt (Keighery *et al.* 2004). Generally the relic native fauna that remain are indicative of this disturbance (Burbidge & McKenzie 1989; Kitchener *et al.* 1980; McKenzie *et al.* 2007) (but see Abbott 2006). Of the native mammals that I detected, *M. fuliginosus* was widespread, *T. vulpecula* occurred at one quarter of the sites and the remaining native mammals were seldom encountered. All other mammals were either agricultural or invasive, with the most frequent of these being *O. aries*, *O. cuniculus*, *V. vulpes* and *M. domesticus*. Native mammals which remain in the Wheatbelt are species that have adapted to, exploited or tolerated the primary environmental disturbance of habitat clearing and fragmentation and according to my results, do not appear to be affected by dryland salinity.

My results are supported by Smith *et al.* (1997) who found that the abundance of *M. domesticus*, *Sminthopsis crassicaudata* (Gould 1844, Dasyuridae) and *Sminthopsis dolichura* (Kitchener, Stoddart & Henry 1984, Dasyuridae) did not decline on saline land. Burbidge *et al.* (2004), also found richness of mammal fauna was unrelated to salinity. However, trapping occurred on naturally saline land for both these studies, rather than anthropogenic saline land. McKenzie *et al.* (2003) focussed on natural and anthropogenic saline land and also found that the richness of mammals and occurrence of *M. domesticus*, *Tarsipes rostratus* (Gervail & Verraux 1842, Tarsipedidae) and *Sminthopsis dolichura* were unrelated to salinity. However, McKenzie *et al.* (2003) did find some native mammals were related to salinity. For example: *Cercartetus concinnus* (Gould 1845, Burramyidae) was widespread, but occurred rarely on saltflats; *Sminthopsis*

gilberti (Kitchener, Stoddart & Henry 1984, Dasyuridae) and *Sminthopsis griseoventer* (Kitchener, Stoddart & Henry 1984, Dasyuridae) were absent from saltflats; and *Sminthopsis crassicaudata* was only recorded from saltflat environments. It is possible that in these cases, relationships with salinity may have been related to species specific food or habitat requirements, or interspecific interactions.

As predicted, assemblages of mammals were generally associated with other environmental factors, rather than salinity. For example, *M. fuliginosus* are positively related to the cover of ground herbs; and *M. domesticus* densities increased with ground cover, leaf litter, rock and woody debris. These habitat variables are indicative of a combination of food availability and shelter (Burbidge *et al.* 2004). However, in some cases it is difficult to determine the significance of associations with some environmental variables (Burbidge *et al.* 2004). For example, abundance of *M. domesticus* and *T. vulpecula* increased positively with potassium and phosphorus respectively. It is possible these associations may be indicative of resource and microhabitat differences between sites, but these factors were not identified in the variables examined here. With the obvious exception of *O. aries*, results here generally support the hypothesis; that mammal fauna exhibit resistance to the disturbance wrought by dryland salinity, and are related to other determinants of distribution and abundance, such as vegetation.

This study focussed on relationships between environmental variables and mammal abundance. However, interspecific interactions may also influence mammal occurrence and abundance. For example, *P. calura* is known to predate on *Mus domesticus* (Strahan 1988) and, accordingly, *M. domesticus* were not detected at the two sites occupied by *P. calura*. *Vulpes vulpes* also predate on other mammals, such as *O. aries*, *O. cuniculus* and *T. vulpecula* (Banks 2000; Greentree *et al.* 2000; McKenzie *et al.* 2007). However, I did not detect a negative abundance dependent relationship between *V. vulpes* and any of these species (linear regressions: $r^2 = 0.147$, $F_{1,10} = 1.719$, $P = 0.219$; $r^2 = 0.010$, $F_{1,10} = 0.096$, $P = 0.763$; and $r^2 = 0.0028$, $F_{1,10} = 0.288$, $P = 0.603$, respectively).

There are some cases where native species may not have been detected in this study. For example, my trapping did not specifically target insectivorous or carnivorous mammals. This potentially excludes observing widespread native insectivores, like Dunnarts *Sminthopsis* sp. (Dasyuridae) and Quenda *Isodon obesulus* (Shaw 1797, Peramelidae), and native carnivores, like the Western Quoll *Dasyurus geoffroyi* (Gould 1841, Dasyuridae) (McKenzie *et al.* 2003; Menkhorst & Knight 2001; Smith *et al.* 1997). However, *Sminthopsis* sp., *I. obesulus* and *D. geoffroyi* are still occasionally trapped using the methodology employed here (Chambers & Dickman 2002; Morris *et al.* 2003; Wilson *et al.* 1986), and it is probable these species were rare or absent at my sites. The WA Department of Environment and Conservation similarly did not detect any of these mammals at the same sites (Keighery *et al.* 2004).

Additionally, increased understorey vegetation may have obscured spotting mammals and thus have led to underestimates of abundance. But, every effort was made

to be meticulous with observations during transect surveys and I did not detect a relationship between mammal abundance and observational area per survey for any species (Carver unpublished data). Furthermore, relationships between climatic variables and abundance of mammal species are not presented in this study. In preliminary investigations, I examined relationships between mammal abundance and climatic variables and found a weak relationship ($r^2 = 0.378$) between abundance of *M. fuliginosus* and average winter temperature between sites only, which was difficult to interpret and possibly spurious (climatic variables derived from each site using ANUCLIM, see Keighery *et al.* 2004 and McMahon *et al.* 1995). Accordingly, analyses of climate and abundance of mammal species between sites was excluded from this study.

Conclusions

The effect of multiple environmental impacts on mammals has received relatively little attention. This study hypothesised and found that non-volant native mammals were resistant to the effects of a compounding environmental change, dryland salinity. Abundance of introduced mammals was also unrelated to salinity, except *O. aries*, which exhibited reduced abundance in saline areas. In general, individual species and assemblages of mammals exhibited associations with other environmental factors. This study supports other studies, which have considered multiple impacts, concluding assemblages of native mammals appear to be resistant to secondary environmental impacts. Resistance of mammals, which survive primary environmental changes, to further environmental change may be a widespread phenomenon.

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